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INVESTIGATION OF MODELS FOR LARGE-SCALE METEOROLOGICAL PREDICTION EXPERIMENTS

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INVESTIGATION OF MODELS FOR LARGE-SCALE METEOROLOGICAL PREDICTION EXPERIMENTS

Introduction

During the past year the City College group continued to work in close collaboration with the Goddard Institute for Space Studies (GISS) on an evaluation of the feasibility of long-range weather prediction through the use of global general circulation models (GCMs). The major emphasis of the study has been on the quality of simulations of the monthly mean state of the atmosphere generated by models from real global initial data at the beginning of the month. Early in the year the last of a series of monthly mean simulations was completed with the original GISS GCM (Somerville et al., 1974), after which attention was transferred to a new "climate model" developed by the atmospheric sciences group at GISS under the direction of James Hansen (Hansen et al., 1978).

A series of experiments was carried out with an early version of the new model, using data for the period October 1976 through February 1977, to determine the credibility of global monthly mean simulations generated by a

coarse-resolution (8° of latitude by 10° of longitude)[1] form of the model. The results of these experiments, as well as those with the GISS GCM, have already been described in a series of technical reports by members of the project staff, and only a brief summary is presented in this annual report.

As in the past, the primary motivation of the project has been to investigate the feasibility of long-range weather prediction with global GCMs. The climate model was designed for the purposes of very long term climate simulation and to test theories of climate change, and was not intended for use as an operational weather forecasting system. However, as it contains the same dynamical and physical ingredients as most numerical weather prediction (NWP) models and GCMs, it is a suitable vehicle for studies of long-range predictability. Furthermore, the new coarse-mesh model is very fast. In its most recent form, the model generates a one-day global simulation on the 8 x 10 grid in four minutes (on an IBM 360/95

[1] In the terminology of the GISS modeling group, the $8^{\circ} \times 10^{\circ}$ grid is sometimes identified as "medium", and the terms "fine" and "coarse" may be used to refer to $4^{\circ} \times 5^{\circ}$ and $12^{\circ} \times 15^{\circ}$ grids, respectively. However, in the context of this report it is appropriate to refer to the 8 x 10 model as "coarse-mesh" or "coarse-resolution" in order to distinguish these experiments from those conducted with the 4 x 5 GISS (Somerville et al., 1974) GCM.

computer), so that a 30-day forecast can be executed in two hours. This is an order of magnitude faster than the 4 x 5 GISS (Somerville) model and permits that many more experiments to be conducted in comparable time.

Of course, the high speed of the new model is achieved mainly at the price of its coarse resolution, which requires certain parameterizations of surface boundary conditions, as well as inherent filtering of smaller-scale features of the initial state, and this may degrade the quality of the simulations. Real data tests of the model such as the monthly mean prediction experiments carried out on this project help to provide realistic estimates of model credibility. If a model is to be used to investigate the causes of climate change and climatic anomalies, it is appropriate to ask how well it can simulate the time-averaged state of the real atmosphere for the next month. In this sense, the monthly mean simulation tests may be viewed as part of the model development program.

Publications during the past year included:

Spar, J., 1977: A summary of monthly mean simulation experiments with the GISS model (GSFC). Third NASA Weather and Climate Program Science Review, November 29-30, 1977, NASA, Goddard Space Flight Center, Greenbelt, Md. NASA Conference Publication 2029, pp. 323-327. Paper No. 58.

Spar, J., J. J. Notario, and W. J. Quirk, 1978: An initial state perturbation experiment with the GISS model. Mon. Wea. Rev., 106, 89-100.

The following technical reports were distributed:

Lutz, R. J., 1978: Experiments in monthly mean simulation of the atmosphere with a coarse-mesh general circulation model. The City College, N. Y., N. Y., 46 pages. (M.A. thesis)

Notario, J. J., 1978: The influence of random initial state errors on monthly mean simulations with a coarse-resolution atmospheric model. The City College, N. Y., N. Y., 46 pages. (M.A. thesis)

Klugman, R., 1978: The influence of initial conditions on monthly mean simulations with a global atmospheric model. The City College, N. Y., N. Y., 42 pages. (M.A. thesis)

Spar, J. and R. Lutz, 1978: Simulations of the monthly mean atmosphere for February 1976 with the GISS model. The City College, N. Y., N. Y., 29 pages. (Accepted for publication in the Monthly Weather Review.)

Spar, J., R. Klugman, R. J. Lutz, and J. J. Notario, 1978: Monthly mean simulation experiments with a coarse-mesh global atmospheric model. The City College, N. Y., N. Y., 56 pages. (Abbreviated version submitted for publication to Monthly Weather Review.)

A paper on "Monthly Forecasting Experiments with Atmospheric Models" was presented in 28 March 1978 by J. Spar at the New York Academy of Sciences.

Three graduate student research assistants--Robert J. Lutz, Jesus J. Notario, and Robert Klugman--completed their master's programs at The City College and resigned from the project staff this past summer. They were replaced in September by two new graduate assistants: Zaphiris Christidis and Ronald Filadelfo. Both Notario and Klugman have remained at GISS (Lutz left to pursue a doctoral program in Maryland), so that there has been

no break in the continuity of the project.

Monthly Mean Simulations for February 1976 with the GISS Model

(A more complete paper on this experiment has been distributed as a Technical Report and accepted for publication in the *Monthly Weather Review*.)

Three monthly mean simulations of the global atmosphere were computed for February 1976 with the GISS model (Somerville et al., 1974) from observed initial conditions on the first day of the month. The first two simulations (designated M1 and M2) were part of a replication experiment in which the identical program, with identical initial and boundary conditions, was repeated on the IBM 360/95 computer, the two runs differing only in the schedule of interruptions and restarts necessitated by other demands on the computer during the month-long forecast. A comparison of these two forecasts provides a measure of the reproducibility of results. Table 1, showing the results of the replication experiment in terms of predicted and observed mean zonal and eddy energies, indicates that the differences between simulations are

Table 1. Zonal available potential energy (P_M), zonal kinetic energy (K_M), and eddy available potential energy (P_E) and eddy kinetic energy (K_E) of standing waves only, for February 1976 over the Northern Hemisphere and the globe, integrated up to the 120 mb level for forecasts M1 and M2 and the observed (O) mean monthly atmosphere. Units: 10^5 J m^{-2}.

	Northern Hemisphere			Globe		
	M1	M2	O	M1	M2	O
P_M	58.9	56.0	49.8	42.3	41.8	35.9
K_M	8.56	8.42	7.21	6.69	6.61	5.97
P_E	2.35	2.45	3.71	1.69	1.71	2.29
K_E	1.14	1.31	2.23	0.91	1.00	1.54

relatively small compared with the simulation errors. Root-mean-square (rms) differences and S1 comparison scores between the two simulations are shown in Table 2 for three synoptic fields and for various geographic regions. The rms errors of replication over the Northern Hemisphere of the monthly mean fields are seen to be approximately 2 mb, 20 m, and 1° K for sea-level pressure, 500 mb height, and 850 mb temperature, respectively, indicating roughly the computational "noise" level of the model.

Table 2. Root-mean-square (rms) differences and S1 comparison scores for February 1976 forecasts M1 vs. M2.

Region	Sea-level Pressure rms (mb)	Sea-level Pressure S1	500 mb Height rms (m)	500 mb Height S1	850 mb Temperature rms (K)
1. Globe	1.5	38	16	21	
2. Northern Hemisphere	1.8	43	19	23	1.2
3. Tropics	0.8	37	5	33	
4. E. Pacific-U. S.	2.1		28		1.2
5. North America	2.5	51	26	20	
6. United States	2.2	48	28	16	1.4
7. Europe	2.1	43	19	25	

The monthly mean simulation skill for February 1976 is generally consistent with that found in three earlier winter month forecasts with the GISS model, as shown in Table 3. Small but consistent skill relative to climatology is indicated over the Northern Hemisphere for the 500 mb heights and 850 mb temperatures, but not for the sea-level pressure field.

Table 3. Summary of rms errors and S1 skill scores for four GISS-model simulations of monthly mean sea-level pressure, 500 mb height, and 850 mb temperature over the Northern Hemisphere. M denotes the model simulation and C represents a "forecast" of climatology.

	Jan. 1973		Jan. 1974		Jan. 1975		Feb. 1976	
	M	C	M	C	M	C	M	C
A.	rms errors							
Sea-level Pressure (mb)	10.0	8.7	8.6	9.2	5.3	6.6	8.8	6.3
500 mb Height (m)	72	94	80	108	62	82	81	99
850 mb Temperature (K)	4.1	4.3	4.7	5.1	4.1	4.5	4.4	4.6
B.	S1 scores							
Sea-level Pressure	81	81	79	89	64	73	75	81
500 mb Height	45	55	53	60	42	52	43	53

In a third simulation for February 1976, to measure the influence of sea-surface temperature (SST) anomalies on the monthly mean forecasts, observed monthly mean SSTs were inserted in place of climatological monthly mean values as surface boundary conditions. The result was a small beneficial impact on the global and hemispheric errors, but not on the regional scores. Over the Northern Hemisphere, the rms errors for sea-level pressure, 500 mb height, and 850 mb temperature were reduced from 8.8 to 7.2 mb, from 81 to 66 m, and from 4.4 to 4.3° K, respectively, while the corresponding S1 scores for the first two fields changed from 75 to 72 and from 43 to 41, respectively. The effect of the anomalous SST field on the simulated synoptic patterns was hardly discernible to the eye.

Monthly Mean Simulation Experiments with a Coarse-Mesh Atmospheric Model

(A more complete paper on this subject has been distributed as a Technical Report. The three Technical Reports by Lutz, Notario, and Klugman also contain additional details on the experimental results summarized briefly below.)

The period October 1976 through February 1977 was chosen for a test of an early version of the new coarse-resolution ($8^\circ \times 10^\circ$) climate model developed at GISS (Hansen et al., 1978). This was a very anomalous winter over North America, with abnormally cold weather in the eastern United States and high temperatures in the west. Four groups of experiments were carried out, all based on global data for the period provided by the National Center for Atmospheric Research (NCAR) and the National Meteorological Center (NMC) and derived from operational NMC analyses.

The version of the coarse-mesh model employed in the experiments described below (version 252) was derived from the GISS model, and employs the same "Matsuno TASU" extrapolation scheme as in Somerville et al. (1974), with a 12-minute time step. However, a number of changes have been made in the model physics, notably in the calculation of radiative transfer, as well as in the parameterization of convection and surface boundary fluxes (Hansen et al., 1978). The model is still undergoing development, and the experiments with version 252 were conducted as part of a program of monitoring progress rather than as a final evaluation of the model.

For the first experiment, the $8^\circ \times 10^\circ$ climate model was initialized with global data for 00 GMT on the first

day of each of the five months. Climatological monthly average SSTs and sea ice fields were used as surface boundary conditions. The 12-hourly outputs of the model were averaged at the end of each of the five month-long forecast runs to produce a set of five monthly mean simulations. The evaluation of the model simulations was limited mainly to the synoptic fields of sea-level pressure, 500 mb geopotential height, and 850 mb temperature, and expressed numerically in terms of rms errors and S1 skill scores. To provide a standard for the evaluation of the model simulations, monthly climatological fields of the three variables, derived from NCAR data, were also evaluated as "forecasts" of the five monthly mean states.

Examination of the observed and simulated monthly mean maps (not reproduced here) reveals that the model failed to simulate adequately the sea-level pressure field. At the 850 mb level, the model exhibited a cold bias at all latitudes, especially in higher latitudes, with an average error over the Northern Hemisphere of -3.5° C for the five months. This is reflected hydrostatically in low geopotential heights in the simulations of the 500 mb level, which average 93 m too low over the Northern Hemisphere. The phase opposition between the cold east and warm west over North America was also poorly simulated by the model, as was the amplitude of

the anomalous long wave pattern at 500 mb associated with the severe North American winter. Rms errors and S1 skill scores of the model (M) over the Northern Hemisphere, together with those for a "forecast" of climatology (C), are shown in Table 4, where the model simulations are seen to be inferior to climatology.

At this stage of the model's development, it is apparently not yet capable of duplicating realistically significant departures from climatology of monthly mean synoptic patterns. A comparison of the January and February Northern Hemisphere results in Table 4 with the corresponding error scores for the GISS model, shown in Table 3, indicates that the coarse-mesh model simulations appear to exhibit even less skill relative to climatology than the $4^{o} \times 5^{o}$ GISS model. (However, as the results are for different years, they may not be comparable.)

In a second simulation experiment with the coarse-mesh model, the climatological monthly mean sea-surface temperatures (SSTs) were replaced with observed monthly mean SSTs derived from satellite radiometer measurements (Brower et al., 1976) and provided on a $2\frac{1}{2}^{o}$ latitude-longitude grid from which four point averages were computed for each coarse-mesh grid point. The magnitude (in ^{o}C) and distribution of the SST anomalies (observed - climatology) is illustrated for the month of January 1977

Table 4. Root-mean-square (rms) errors and S1 skill scores of monthly mean model simulations (M) and of climatology (C) over the Northern Hemisphere for winter 1976-1977.

A. rms errors

		Oct.	Nov.	Dec.	Jan.	Feb.
Sea-level pressure (mb)						
	M	5.3	7.2	6.1	7.2	7.8
	C	3.0	2.9	3.5	5.9	4.4
500 mb height (m)						
	M	104	114	112	131	119
	C	39	40	43	73	55
850 mb temperature (^{o}K)						
	M	5.1	5.2	5.5	5.9	5.4
	C	2.2	2.1	1.9	2.7	2.3

B. S1 skill scores

		Oct.	Nov.	Dec.	Jan.	Feb.
Sea-level pressure						
	M	95	102	90	89	87
	C	65	53	51	64	62
500 mb height						
	M	52	71	67	67	62
	C	47	42	43	57	48
850 mb temperature						
	M	66	65	67	67	62
	C	49	47	39	51	43

in Fig. 1 in the form of a digital global array. (The same data source was used for the GISS model SST experiment described earlier.)

The response of the model atmosphere to SST anomalies is a complex non-linear combination of local and remote effects resulting from the parameterization of the surface fluxes of heat and moisture in terms of air-sea temperature differences. Locally, we find over positive SST anomalies ("hot spots") higher 850 mb temperatures, lower sea-level pressures, and slightly higher 500 mb heights in the model simulations with the observed SSTs than in the runs with climatological SSTs. However, as shown in Table 5 by the rms differences and S1 comparison scores between the two simulations--A, with the observed SSTs and M, with the climatological SSTs--the general impact of the SST anomalies on the monthly mean simulations is relatively small over the Northern Hemisphere, especially at the 500 mb level where it is virtually negligible. Furthermore, a comparison of the error scores for the A and M simulations, shown in Table 6 for the Northern Hemisphere, reveals no <u>beneficial</u> impact whatsoever resulting from the use of observed SSTs. Whether this is due to poor quality of the SSTs or insensitivity of the model, or both, is not known. As noted earlier, the GISS model experiment did indicate a small beneficial

TAU = 37308.0 ANOMALY SST S FOR JAN 1977 (OBS.-CLIM.). DEGREES KELVIN DAY 1554. HOUR 12.0

J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	LAT	MEAN
	-180			-150			-120			-90			-60			-30			0			30			60			90			120			150				
24																																					90.0	
23																																					82.2	
22																																					74.3	
21											0					1	[illegible]	-1	0	0																	66.5	0
20	0	0		-1	-2					-1	2		3	1	-1	-2	0	0	0		1															-1	58.7	0
19	-3	-2	-2	-1	-1	0								-1	6	-2	-1	0																0	-2	-2	50.9	-1
18	-4	-2	-1	-1	0	1							7	11	4	0	-1			2		2	1	6									9	5	2	-6	43.0	2
17	0	0	0	1	1	0						6	2	1	1	2	1	2			1	1										4		3	2	0	35.2	1
16	1	1	1	1	1	0	0			1		2	2	2	2	1	1															2	1	0	1	0	27.4	1
15	-1	0	0	0	0	-1	-1	2			0		0	1	1	1	0						2		1	3		1			0	0	0	0	-1	-1	19.6	0
14	-3	-3	-2	-2	-3	-1	0	-1	0	1	-1		0	-1	-1	-1	3								1	1		0		0	-1	-2	-3	-3	-3	-3	11.7	-1
13	-2	-1	-2	-2	-2	-1	-1	-1	-3	-1	-1			-2	-2	-1	0	-1	-2					1	0	0	1	0	0	0	0	-1	-1	-1	-3	-3	3.9	-1
12	1	-1	-1	0	0	0	0	0	0	-1						-1	-1	-1	-2	-3				1	0	0	-1	-1	0	-1		0		-3	-2	-1	-3.9	-1
11	-3	-1	0	0	0	0	0	-1	0	1	1					0	0	0	-1	0				0	-1	0	-1	-1	-1	0	1	2	1	-1	-2	-2	-11.7	0
10	0	-1	-1	-2	-2	0	0	1	1	0	0					0	0	0	0	0			0	1	1	0	0	0	-1	1				0	-1	-1	-19.6	0
9	0	0	0	0	-2	0	0	1	2	2	1				0	0	1	2	1	0			1	2	2	2	2	2	2	1					0	0	-27.4	1
8	0	1	1	2	1	-1	-2	-2	0	2	3			3	0	1	0	-1	-1	0	1	0	0	0	0	0	0	0	0	2	2	2			0	-1	-35.2	0
7	2	1	1	1	0	-1	-2	0	0	-1	1		2	2	-1	0	-1	1	1	-2	-3	-1	-3	-4	0	1	1	-1	0	0	0	0	0	0	0		-43.0	0
6	0	0	1	0	0	0	1	1	1	-1	-1		0	-1	-2	-1	-1	-1	-1	-2	-2	0	0	-1	-2	-3	-3	-1	0	-1	-1	1	1	1	0	0	-50.9	0
5	1	0	0	-3	-2	-1	2	3	3	2	1	1	-1	-1	0	0	0	1	0	0	0	0	-1	-1	-1	-1	-2	-1	-2	1	-1	1	1	-3	-4	0	-58.7	0
4	-2	-2	-1	0	-1	-1	-1	-1	0	0	-1	-2		-2	1	2	3	2	2	1	-1	-2	-1			-1								-1	-2	-2	-66.5	-1
3	0	-1	0	-1	-1									-2	0	0																				0	-74.3	-1
2																																					-82.2	
1																																					-90.0	
J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	LAT	MEAN
	-180			-150			-120			-90			-60			-30			0			30			60			90			120			150				

Fig. 1 Sea-surface temperature anomaly (^{o}K), January 1977.

Table 5. Root-mean-square (rms) differences and S1 comparison scores between monthly mean simulations computed with observed (A) versus climatological (M) sea-surface temperatures. October 1976 through February 1977. Northern Hemisphere only.

	1976			1977	
	Oct.	Nov.	Dec.	Jan.	Feb.
rms difference					
Sea-level pressure (mb)	1.6	1.7	2.4	2.0	2.1
850 mb temperature (^{o}C)	1.6	1.5	2.1	1.8	1.7
500 mb height (m)	12	17	24	24	21
S1 comparison score					
Sea-level pressure	35	38	38	41	35
850 mb temperature	28	28	33	31	25
500 mb height	15	18	22	22	20

Table 6. Root-mean-square (rms) errors and S1 skill scores of monthly mean simulations computed with observed sea-surface temperatures (A) compared with errors (from Table 4) of simulations computed with climatological SSTs (M). October 1976 through February 1977. Northern Hemisphere.

		1976			1977	
		Oct.	Nov.	Dec.	Jan.	Feb.
rms errors						
Sea-level pressure (mb)	A	5.5	7.4	6.6	7.4	8.2
	M	5.3	7.2	6.1	7.2	7.8
850 mb temperature (^{o}C)	A	5.2	5.3	5.3	6.0	5.6
	M	5.1	5.2	5.5	5.9	5.4
500 mb height (m)	A	105	112	112	135	116
	M	104	114	112	131	119
S1 skill scores						
Sea-level pressure	A	98	104	92	92	93
	M	95	102	90	89	87
850 mb temperature	A	72	69	69	75	68
	M	66	65	67	67	62
500 mb height	A	53	71	70	76	61
	M	52	71	67	67	62

of the observed SSTs.

A third group of coarse-mesh model experiments was carried out to investigate the effects of systematic alterations in initial conditions on the monthly mean simulations for October 1976 and January 1977. In one set of computations, the month-long run was started with data for the second and third day of the month, respectively, instead of the first, to test the sensitivity of the monthly mean simulations to the arbitrary choice of initialization time. In still another computation, the model was initialized with time-averaged initial conditions based on the first five 12-hourly data sets of each month, while in the final experiment of this group the model was re-initialized for the monthly run with the average of the first five days of model output. The latter two computations were carried out to test a hypothesis that smoother initial conditions would produce more realistic monthly mean simulations.

Shifts of one and two days in the initialization time were found to produce only small, but not trivial, changes in the monthly mean synoptic fields. The rms errors and S1 skill scores of the October 1976 and January 1977 simulations computed from shifted initial conditions are similar to those shown in Table 6. Over the Northern Hemisphere, the impact of shifting the initialization

time, as expressed by the rms differences between simulations from shifted and unshifted initial conditions, was found to be (averaged over the two months) 1.8 mb, 1.5° C, and 19 m for a one-day shift, and 2.5 mb, 2.0° C, and 29 m for a two-day shift, for sea-level pressure, 850 mb temperature, and 500 mb height, respectively. These impact scores are, of course, much smaller than the simulation errors, and may be representative of the inherent minimal error of monthly mean simulations associated with the arbitrary choice of initialization time.

The use of time-averaged initial conditions, whether of observed fields or of model output, produced no beneficial effects. The rms errors and S1 skill scores were found to be essentially unaltered by the use of either method of smoothing. The impact of the re-initialization method (with time-averaged initial conditions computed from the first five days of model output) was, in fact, negligible.

The final experiment with the coarse-mesh model was a "noise-level" estimation for October 1976 based on the multiple initial state random perturbation method (Chervin and Schneider, 1976; Spar et al., 1978), with initial global rms errors of 3 ms^{-1} in wind components, 1° C in temperatures, and 3 mb in sea-level pressures. Four perturbations (P1 through P4) of the "control" initial

state were generated, yielding a total set of five monthly mean simulations. As shown in Table 7, differences among the five simulations were virtually negligible over the Northern Hemisphere, in terms of rms differences and S1 comparison scores, compared with the simulation errors in Table 6. Average rms differences over the hemisphere among the simulations are approximately 1 mb, 1° C, and 10 m for sea-level pressure, 850 mb temperature, and 500 mb height, respectively. These values are smaller than those found by Spar et al. (1978) in the corresponding experiment for January 1975 with the $4^{\circ} \times 5^{\circ}$ GISS model, which may be a reflection of either a less active month or the coarser resolution of the climate model.

The geographical distribution of the model noise level, as represented by global maps of the standard deviations of the simulated variables (not reproduced here), shows an increase in noise level from negligible values near the Equator to maximum values in high latitudes, but with considerable zonal variations as well, apparently due to different responses over land than over sea. However, the influence of random initial state errors on the monthly mean simulations is insignificant compared with the simulation errors, indicating both stable model behavior and the need for further model improvement.

Table 7. Root-mean-square (rms) differences and S1 comparison scores over the Northern Hemisphere between monthly mean simulations for October 1976. M denotes control simulation. P1, P2, P3, and P4 represent simulations from four different random perturbations of the control initial conditions.

		P1 - M	P1 - P2	P1 - P3	P1 - P4
Sea-level	rms difference (mb)	0.8	1.0	1.1	1.3
Pressure	S1 comparison	23	26	27	29
850 mb	rms difference (^{o}C)	0.9	0.9	0.9	1.0
Temperature	S1 comparison	16	18	17	19
500 mb	rms difference (m)	9.1	9.0	9.4	11.8
Height	S1 comparison	10	10	11	14

Current Activities and Plans for the Future

The simulation experiments described above were part of a preliminary study of the performance of the climate model at an early stage in its development (version 252). Since the inception of those experiments, the model has undergone several changes in physics, dynamics, and numerics (Hansen et al., 1978). At the end of October 1978, a new series of monthly mean simulation experiments was started for the same five-month period, October 1976 through February 1977, but with a revised version of the model, version 391. As the analysis of results from the new computations is still in progress, they are not included in this report, but will be described later.

Although a description of the climate model lies outside the scope of this report, a brief list of changes from version 252 to version 391 is given below.

1. Leapfrog extrapolation replaced the TASU-Matsuno method (Somerville et al., 1974), and the time step for the $8^{\circ} \times 10^{\circ}$ grid was increased from 12 to 15 minutes. The running time of the model has been reduced from eight to four minutes per simulated day.
2. Fourier smoothing is used near the poles.
3. Changes have been introduced in the schemes for

boundary layer fluxes, dry and moist convection, radiative transfer, and vertical differencing.

4. Potential temperature is now a prognostic variable.
5. Ocean temperatures and ice coverage are interpolated daily from monthly averages.
6. Vertical diffusion is omitted.
7. Prediction of snow, groundwater, and ground temperature conserves moisture and energy, and large-scale precipitation occurs when mean relative humidity exceeds 100%.

In addition to repeating the five monthly mean simulations with version 391 on the $8^{\circ} \times 10^{\circ}$ grid with climatological surface boundary conditions, we are performing another SST anomaly experiment, but with the observed SST values processed differently. In the new computation, the observed SSTs on the $2\frac{1}{2}^{\circ}$ grid will be spatially averaged over the $8^{\circ} \times 10^{\circ}$ box represented by each ocean gridpoint, as was done with the climatological SST data. Computations are also being carried out with version 391 on a $4^{\circ} \times 5^{\circ}$ grid, and the results with the two resolutions will be compared. Additional experiments are also planned to test the sensitivity of the climate model to variations in surface boundary conditions, including snow cover and ground moisture. The model will also be tested on the cold winter of 1977-1978.

References

Brower, R. L., H. S. Gohrband, W. G. Pichel, T. L. Signore, and C. C. Walton, 1976: Satellite derived sea-surface temperatures from NOAA spacecraft. NOAA Technical Memorandum NESS 78, Washington, D.C., June 1976. 74 pages.

Chervin, R. M. and S. H. Schneider, 1976: On determining the statistical significance of climate experiments with general circulation models. J. Atmos. Sci., 33, 405-412.

Hansen, J. E. and collaborators, 1978: Preliminary test of a coarse-resolution climate model. Goddard Institute for Space Studies, N. Y., N. Y. (Unpublished)

Somerville, R. C. J., P. H. Stone, M. Halem, J. E. Hansen, J. S. Hogan, L. M. Druyan, G. Russell, A. A. Lacis, W. J. Quirk and J. Tenenbaum, 1974: The GISS model of the global atmosphere. J. Atmos. Sci., 31, 84-117.

Spar, J., J. J. Notario, and W. J. Quirk, 1978: An initial state perturbation experiment with the GISS model. Mon. Wea. Rev., 106, 89-100.